THREE-DIMENSIONAL MODELING OF CRATER DEGRADATION VIA THE EFFECTS OF IMPACT INDUCED SEISMIC SHAKING, WITH COMPARISONS TO CRATER COUNT DATA.

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Introduction: In recent years, spacecraft observations of asteroids such as 25143 *Itokawa*, *951 Gaspra*, *243 Ida*, *253 Mathilde*, *21 Lutetia*, *433 Eros*, and *4 Vesta* have shown the overriding dominance of impact processes with regard to the structure and appearance of these often irregularly shaped bodies. In a previous work [1], I investigated the relatively unexplored area of seismic shaking as a cause for the downslope motion of regolith and crater degradation on this type of object. This early work showed that seismic shaking is, in all likelyhood, a dominant source for surface modification on small bodies in general, and the cause for the paucity of small craters on asteroid *433 Eros,* in particular. In the present work, I have extended the theory and model development presented in [1] from a analytically-based, general 'global'-scale view of seismic effects to a more numerically-based, regional or local-scale view of the seismic effects of individual impacts. Two forms of numerical models were utilized to perform this work: (1) a numerical 'shake-table', and (2) a three-dimensional terrain evolution model.

Numerical Shake Table: To evaluate the seismic effects of an individual impact at some distance *r* from the impact site, a numerical shake-table was utilized which takes the accelerations recorded in a series of synthetic seismograms (see [1] for a detailed description) and applies them to a hypothetical regolith layer resting on a slope of variable angle, and placed in a low, asteroid gravity field (*Fig.* 1). For this numerical 'experiments,' I use a form of Newmark slide-block analysis, which can be applied when the regolith layer thickness under consideration is much smaller than the seismic wavelengths involved. This assumption works well for all but the highest impact seismic frequencies, which are the most quickly lost by attenuation. Under this restriction, we can approximate the motion of a mobilized regolith layer by modeling the motion of a rigid block resting on an inclined plane (for discussions of the forces involved, see [2]). I compute the accelerations imparted to the block by the asteroid's surface gravity (static loading) and seismically shaking slope (dynamic loading) to obtain an overall block (layer) displacement. The amount of downslope motion for both cohesive and non-cohesive regoliths is computed as a function of impactor size/mass, impact velocity, target surface gravity, distance from the impact site (among other parameters), and general fits are developed. Figure 1 shows a schematic view of this model.

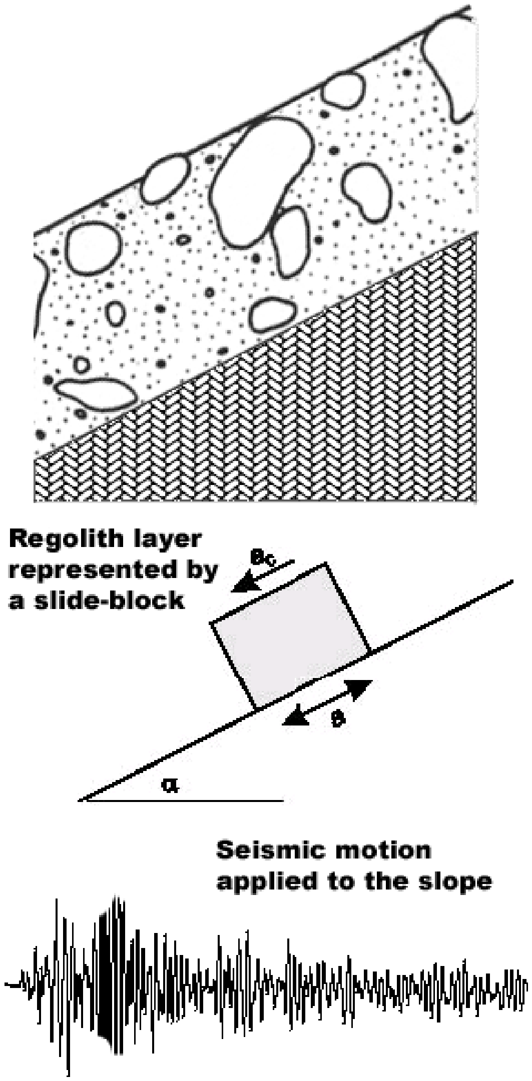

Figure 1: *a schematic representation of the numerical 'shake table' used to determine the amount of downslope regolith motion resulting from a particular complex seismic signal.*

Terrain Evolution Model: The results from the numerical shake-table are applied in a Cratered Terrain Evolution Model (CTEM) which utilizes recent advances in the impact cratering scaling-laws [3,4] to produce a fully 3D model of crater production and erosion on a given (airless) target surface, which includes regolith generation, downslope regolith migration, and automatic crater counting.

Impact Cratering Scaling-Laws: The impact cratering scaling relationships are used to relate the size of an impactor to the size of a resulting crater on a given target surface, given several impact parameters [3]. Cratering on a small target body falls into neither of the two commonly used regimes: gravity and target strength are both important to the size of the final crater. I have therefore adopted the general solution to the transient crater volume scaling relationship given in [3]. The application of a general solution to the crater volume scaling-law permits me to also adopt a general solution to the ejecta velocity scaling relationships [4], allowing me to accurately compute ejecta blanket thickness as a function of distance from a given impact site in a variety of impact environments.

Downslope Regolith Migration: A key feature of the CTEM is the inclusion of downslope regolith migration, triggered either by slope instability or by the seismic motion generated by nearby impacts. This regolith motion is computed in finite-differencing fashion following each impact, using the slope degradation theory described in [1], and which reproduces the analytical model behavior shown in that work. As mentioned above, the general results of the numerical shake-table experiments are applied here, as shown in Figure 2.

Crater Superpositioning and Erasure: In general, impact craters on airless bodies are erased by three mechanisms: subsequent impacts, which erode and modify the underlying crater; coverage by the ejecta thrown up by other, nearby impacts; and the downslope movement of regolith due to slope instabilities and impact-induced seismic shaking. If a portion of a crater's profile is either excavated by a subsequent impact or eroded by downslope regolith motion to less than 10% of its original vertical relief, or if the crater's rim or bowl is covered over by regolith to a depth equal to 90% of its current vertical relief, than that small portion of the crater is considered to be "erased" and is no longer included. When the crater has 'lost' over 1/3-2/3 of it's surface area (user defined), it is considered to be no longer countable.

Applications to 433 Eros: There are two questions relative to asteroid *433 Eros* to which this model combination will be applied: (1) does this more sophisticated model reproduce the results of our previous work [1] and indicate seismic shaking as the primary cause for the paucity of small craters observed, and (2) can this new model reproduce the findings of Thomas & Robinson [5], in that single, large impacts can produce observable variation in the asteroid's crater population as a function of distance from the large impact. Both questions can be answered in the affirmative (*Fig.* 2).

References: [1] Richardson, J.E., *et al.* (2005), *Icarus*, **179**, 325-349. [2] Lambe, T.W. & Whitman, R.V. (1979), *Soil Mechanics*, Whiley & Sons. [3] Holsapple, K.A. (1993). *Ann. Rev. Earth & Plan. Sci.*, **21**, 333-373. [4] Richardson, J.E., *et al.* (2007). *Icarus*, **190**, 357-390. [5] Thomas, P.C & Robinson, M.S., *Nature*, **436**, 366-369.

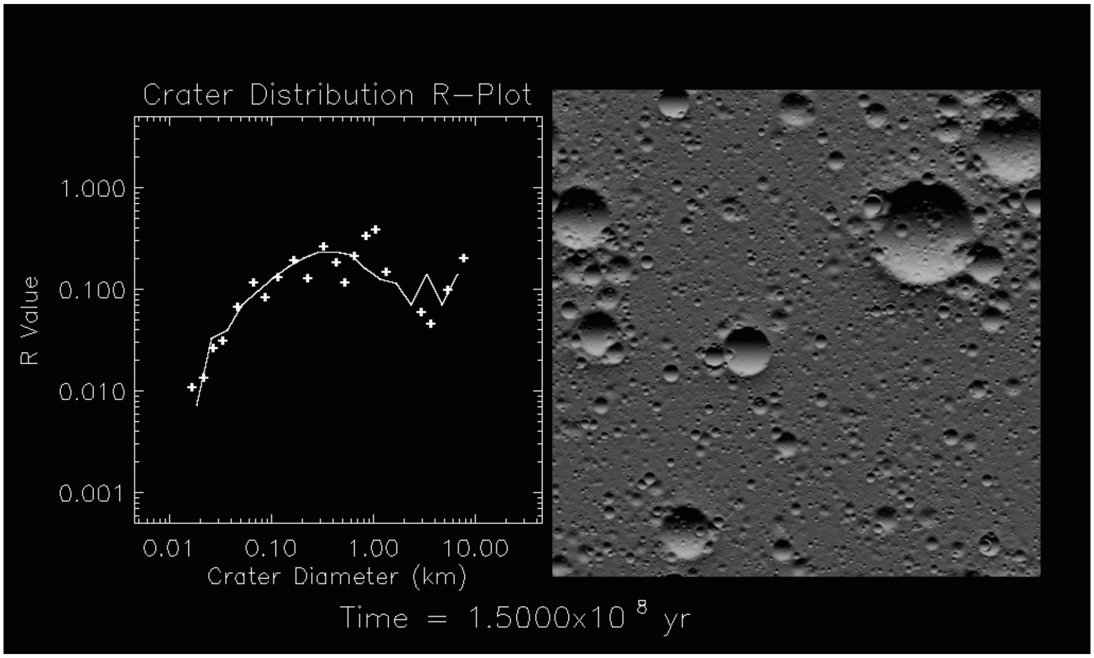

Figure 2: *A CTEM model run wihc accurately reproduced the paucity of small craters on 433 Eros, when exposed to a Main Belt model mpacor flux (crosses = crater counts, solid line = model).*